LA-UR-94-1832

CONCEPTUAL DESIGN FOR A FAST NEUTRON IONIZATION CHAMBER FOR FUSION REACTOR PLASMA DIAGNOSTICS

W. C. Sailor, Cris W. Barnes, G. A. Wurden and R. E. Chrien
Los Alamos National Laboratory
Los Alamos, NM 87545 USA

American Nuclear Society Eleventh Topical Meeing on the Technology of Fusion Energy, June 19-23, 1994, New Orleans, LA

CONCEPTUAL DESIGN FOR A FAST NEUTRON IONIZATION CHAMBER FOR FUSION REACTOR PLASMA DIAGNOSTICS

W. C. Sailor, Cris W. Barnes, G. A. Wurden and R. E. Chrien
Los Alamos National Laboratory
Los Alamos, NM 87545 USA
(505) 665-5348

ABSTRACT

A conceptual design for a radiation-hard "pointing" fast neutron ionization chamber that is capable of delivering a 1 MHz countrate of T(D,n) events at ITER is given. The detector will use a ~1 cm^3 volume of CO_2 fill gas at 0.1 bar pressure in a ~500 V/cm electric field. The pulse widths will be ~10 ns, enabling it to operate in a flux of ~$6x10^{13}$ DT n/cm^2/sec. A special collimator design is used, giving an estimated angular resolution of 4.5 degrees HWHM.

I. INTRODUCTION

The International Thermonuclear Experimental Reactor (ITER) is a worldwide effort to construct a reactor that operates at nearly 100% on the D(T,n) reaction. The reactor conceptually has an major and minor radius of 6 m and 2.2 m, respectively, and a total DT source strength of $3.5x10^{20}$ n/sec. In order to observe the behavior of short (~ms) time-scale instabilities in small (~0.1 m^3) volume of plasma, we envision a 14-MeV neutron detector placed 0.5 m from the outer wall that operates at 1 MHz.

Ionization chambers have been used for neutron detection for many years,[1] and its use as a fast, radiation hard detector for fission reactor measurements[2] and high energy physics research[3] has grown. The theory and practice of these detectors are well documented[4,5] and they offer increased radiation resistance versus, e. g., scintillating fibers[6,7] For high-speed counting, small detector dimensions and a low-pressure fill gas must used. The total 14 MeV neutron reaction cross section for any nucleus that is found in candidate fill gases is about 1 barn, meaning that a detector that holds 1 cm^3 of gas at STP will have a ~0.3 GHz rate of ionization events. The fill gas should give both high electron drift speed and good stopping power. The emphasis of this paper is on simulations of collimator performance using the code MCNP[8] and detector response using a modification of the code of Sailor, Prussin and Derzon.[9]

II. DETECTOR DESCRIPTION

The detector consists of six small ionization chambers that are collimated so that they view only 7% of the total DT neutron flux, or $4x10^{12}$ n/cm^2/sec. An efficiency-area product per chamber for events crossing discriminator threshold of $8x10^{-8}$ cm^2 gives the desired net count rate. The detectors are of annular shape, with a 1 mm radius anode, 2 mm radius cathode. The length is 10 cm and the pressure 0.10 bar CO_2. An alternative fill gas is CF_4. At ITER, where a 14 MeV neutron flux of 4 x 10^{12} n/cm^2/sec is expected (after collimation), the rate at which combined elastic and inelastic scatters will occur, (with their typically ~1 barn cross section) is about 40 MHz. The discriminator level is set so that only the large pulses from heavy ion recoils will trigger the detector. Light particles are produced by other reactions, but their low stopping power produces small pulses within the fill gas. Some carbon and oxygen reactions are listed in Table I below:

Table I. Some Important Neutron-Induced Reactions at 14 MeV Incident Energy[10]

Reaction	Oxygen	Carbon
total	1.6 barn	1.3 barn

elastic scatter	1.0	0.80
inelastic scatter	0.5	0.26
(n,α)	0.1	0.07
(n,p)	0.05	0.001

Drift speeds of $7x10^6$ cm/sec and $13x10^6$ cm/sec are possible in CO_2 and CF_4, respectively, based on a compilation of experimental data.[11] This would require an applied potential across the 1 mm cathode/anode gap of 50 Volts for CO_2 or 25 Volts for CF_4. The electrons will be swept away in 14 ns and 8 ns in the two cases. For the heavy ions we assume the primary energy loss mechanism is by ionization,[12] giving about 4 fC of free electrons per MeV of slowing within the fill gas.[13] The current pulse is then about 400 nA for a 1 MeV energy loss, without requiring multiplication. The positive ion drift time is about 10^3 longer, giving a contribution to the baseline current.

III. NEUTRON RESPONSE OF DETECTOR

Our simulations have been limited to the case of pure CO_2 fill gas, but the results can be considered to hold qualitiatively for the CF_4 fill gas as well. The processes simulated in the code of Sailor, Prussin and Derzon are the scattering from oxygen and carbon nuclei, C(n,α) and O(n,α) reactions, charged particle slowing and wall or anode interactions and energy dependent ionization. The electrons liberated by ionization produce an amplitude in proportion to the fraction of the full potential they fall through. We have considered a 14 MeV flux of neutrons incident on a single detector and calculated the probability that neutron interactions will lead to an event crossing a discriminator threshold.

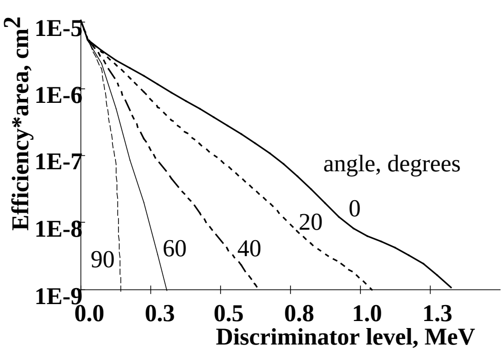

Figure 1. Efficiency-area product of detector as a function of incident 14 MeV neutron angle and discriminator level. Neutrons arriving far off-axis have a lower probability of producing large pulse-height events.

The efficiency-area product for incident DT neutrons is given in **Figure 1** as a function of discriminator level and in **Figure 2** as a function of angle. The signals are produced mostly by recoil nuclei, where the mean energy loss is about 1 to 1.5 MeV/cm. When the anode/cathode gap (here 1 mm) is small, the largest pulses are produced by on-axis neutrons that scatter at an angle near 180°. If the incoming neutrons enter at an angle off-axis, the efficiency drops because the recoil nucleus has a shorter average track length. The signals from α particles, with their low comparable energy loss, are of little importance in this detector. The angular resolution of the bare ionization chamber can be approximated as a gaussian with σ = 12.8°.

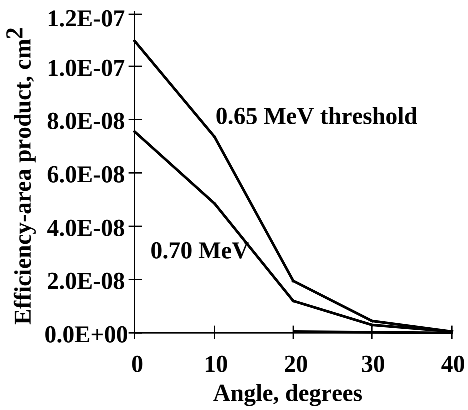

Figure 2. The angular resolution functions can be approximated as a gaussian with σ=13°. It is desired to have an efficiency-area product of about $8x10^{-8}$ cm^2 at 0°.

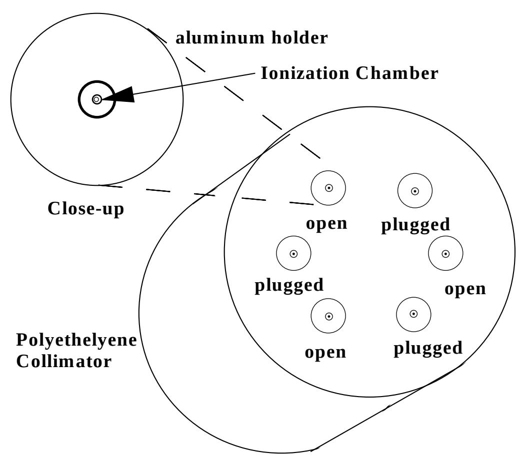

Figure 3. The detector/collimator concept, with the six ionization chambers placed into aluminum holders. There are open holes parallel to the collimator axis exposing three of the detectors. The other three holes are plugged.

The conceptual design of the detector/collimator is shown in **Figure 3**.[14] The ionization chambers are set into blocks of aluminum. The uncollided DT neutrons arrive axially. In this design the collimator holes are 1.75 cm in radius. There are six ionization chambers in the collimator, arranged in a circular configuration. The collimator is 9.1 cm in radius and

35 cm long. Of the six holes for collimation, three are plugged with polyethylene. The discriminator output for the three chambers that have holes are fanned-in together and the three that have plugs are fanned-in together. It is the *difference* between these two discriminator-crossing rates that is the net count rate.

In MCNP, a model source at nominally 200 cm was moved back and forth horizontally, resulting in a calculation of the efficiency-area product versus angle. Included in the calculation is the effect of the angular-dependence of the probability that the signal will cross a 0.72 MeV discriminator, as taken from **Figure 2.** The angular efficiency functions, shown in **Figure 4**, cancel each other out almost perfectly at angles greater than 10°, giving a net angular resolution of 4.5° HWHM. Such an angle provides resolution of ~10% of the minor radius of the tokamak. Note here that because there are three detectors adding together to produce the net signal (after subtracting the other three detector's signals) the on-axis efficiency-area product is three times that for a single detector. Also shown is the case of the sum of three bare detectors, minus collimator. The angular dependence to the response is due to wall effects. The directionality of the bare detector allows use of a much more compact collimator to achieve spatial resolution of the neutron emission profile.

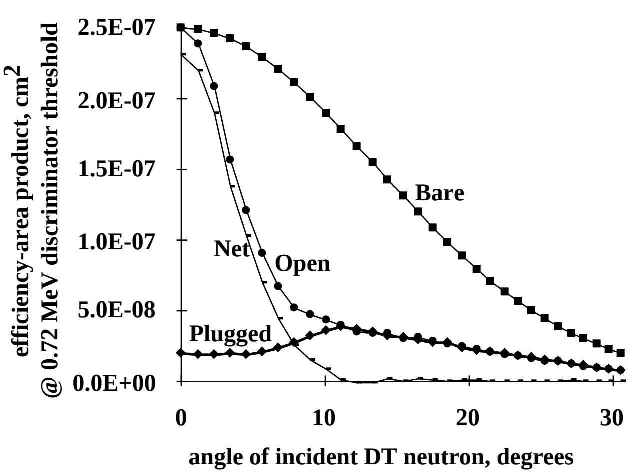

Figure 4. Detector response versus incident angle of the detector/collimator system, including a 0.72 MeV discriminator setting. The difference between the countrates in the open and the plugged holes is the net countrate. The angular response of the bare ionization chamber is also shown.

IV. PILEUP

The events in the detector that *do not* cross threshold constitute a background that can interfere with the normal counting of the detector. The pulse-height distribution in the detector (the derivative of Fig. 1) is given roughly as a negative exponential with a mean value α = 0.09 MeV. In order to cross the 0.72 MeV threshold, about 8 of these average pulses would have to occur in the resolving time of the detector, τ = 10 ns. The zero-threshold efficiency-area product for the detector is calculated to be 1.0×10^{-5} cm^2, neglecting any charged-particle producing interactions in the construction materials. The interaction rate from the uncollided flux is r = 40 MHz, giving a mean value of $r\tau = 0.4$ due to the uncollided flux. The total rate of DT interactions in the detector, however, will include DT neutrons that have scattered in the collimator or in other room materials and may be as much as five times higher. The mean number of simultaneous pulses in the detector is then $r\tau < 2$.

A simple pileup calculation was performed. The path was taken that facilitates the use of convenient functional forms for the pileup rate equations. We take the pulse height distribution of events not crossing threshold to be a gaussian with a mean and a standard deviation of α. The number of events occurring simultaneously in the detector is taken as a gaussian with mean $r\tau$ and standard deviation $\sqrt{r\tau}$. The rate at which the discriminator, set at a threshold H, will trigger from pileup is given by:

$$\text{(1)} \qquad R_P = \frac{1}{\tau} \ \operatorname{erfc}\left(\frac{H/\alpha}{\sqrt{2r\tau}}\right),$$

which is proportional to the area under the gaussian curve above the threshold. From this equation, we have a pileup count rate of R_P < 3 Hz, which is insignificant. More extensive calculations of this type are possible, but they are not believed to be warranted because of the uncertainties in the true background intensity and pulse height distribution.

V. CONCLUSIONS

The detector will produce 1000 net counts every 1 msec, which should be good for temporal/spatial D(T,n) reaction rate measurements. The electronics will be very simple and the detector and collimator promise to be lightweight and portable. Prototype testing has been performed with a scintillating-fiber detector/collimator over this last year.[15] At ITER, this prototype detector probably could not be used because the radiation damage would limit the amount of time a fiber detector could be placed near the reactor. The small ionization chamber can provide a radiation-hard replacement for the fibers.

ACKNOWLEDGEMENT

This work supported by DOE contract W-7405-ENG-36.

REFERENCES

1. T. W. Bonner, "Ionization Of Gases By Neutrons", *Phys Rev. 43* (1933) 871.

2. N. W. Hill, J. T. Mihalczo, J. W. Allen and M. M. Chiles, "Optimization of Nanosecond Fission Ion Chambers for Reactor Physics Applications", *IEEE Trans. Nuclear Science, NS-22* (1975) pp. 686.

3. B. Zhou, D. Warner, J. Rohlf, D. Osborne, A. Marin, W. W. Lu, G. Hopkins, T. Coan, J. Beatty and S. Ahlen, "Performance of Small-Radius Thin-Wall Drift Tubes in an SSC Radiation Environment at the MIT Research Reactor", *IEEE Trans. Nuclear Science, NS-37* (1990) pp. 1564.

4. G. F. Knoll, *Radiation Detection and Measurement*, John Wiley and Sons, New York, 1979.

5. G. Grosshoeg, "Neutron Ionization Chambers", *Nucl Inst Meth. 162* (1979) 125.

6. L. Linssen, "Performance of the UA-2 Scintillating Fiber Detector" *Proceedings of the Workshop on Scintillating Fiber Detector Development for the SSC, Fermi National Accelerator Laboratory, Batavia, Illinois, Nov. 14-16, 1988*, pg. 7, and other reference therein.

7. W. C. Sailor, Cris W. Barnes, R. E. Chrien and G. A. Wurden, "Conceptual Design for a Scintillating-Fiber Neutron Detector for Fusion Reactor Plasma Diagnostics", *Proceedings of the 10th Annual High-Temperature Plasma Diagnostics Conference, Rochester, NY, May 9-12, 1994*, to be published in *Rev. Sci. Inst.*

8. J. F. Briesmeister, Ed., "MCNP- A General Monte Carlo N-Particle Transport Code", Version 4a, LA-12625-M, November 1993, Los Alamos National Laboratory, Los Alamos, NM 87545.

9. W. C. Sailor, S. G. Prussin and M. S. Derzon, "A Monte Carlo Calculation of the Response Function for a ^{3}He Ionization Chamber", *Nucl. Inst. Meth A270* (1988) 527.

10. D. I. Garber and R. R. Kinsey, "Neutron Cross Sections Volume II, Curves, BNL-325, Ed. 3", Brookhaven National Laboratory, Upton, NY, 1976.

11. A. Peisert and F. Sauli, "Drift and Diffusion of Electrons in Gases: A Compilation" CERN 84-08, July, 1984.

12. J. F. Ziegler, Ed., "Handbook of Stopping Cross Sections for Energetic Ions In All Elements", Vol. 5 of *The Stopping and Ranges of Ions in Matter*, Pergamon Press, New York, 1980.

13. W. P. Jesse and J. Sadauskis, "Ionization in Pure Gases and the Average Energy to Make an Ion Pair for Alpha and Beta Particles", *Phys. Rev. 97*, (1955) 1668.

14. This collimator conceptual design is very similar to that which we proposed in ref. 7.

15. G. A. Wurden, R. E. Chrien, Cris W. Barnes, and W. C. Sailor, "A Scintillating-Fiber 14-MeV Neutron Detector on TFTR During DT Operation", *Proceedings of the 10th Annual High-Temperature Plasma Diagnostics Conference, Rochester, NY, May 9-12, 1994*, to be published in Rev. Sci. Inst.